First results of Neptune observations with Herschel

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Scientific Context

• Neptune’s atmosphere is composed mainly of H$_2$ and He, and has a large CH$_4$ abundance in its troposphere. It also contains some other minor compounds: CO, H$_2$O, hydrocarbons, CO$_2$, and HCN.

• Some important open questions:
  - What is the D/H ratio? Implications on the composition of the icy grains that formed Neptune?
  - What is the CH$_4$ abundance in the stratosphere? Implications for meteorological and vertical transport?
  - What are the CO and H$_2$O profiles in the stratosphere? What is the flux of external oxygen? Implication for the nature of oxygen sources (micrometeorites, comets, rings).
Herschel Observations

- Herschel Observations: PACS and SPIRE full range spectra of Neptune - on Oct. 30/31 2009 - altogether covering the 55-670 micron range.

- Neptune’s angular diameter was of about 2.3”, so unresolved with the Herschel PSFs.

- Expected detectable lines: HD (56,112 μm), CH$_4$(87,95 119,156, ... μm) , CO(162, 186, ... μm ) and H$_2$O(66,75,82, 108, 125, .. μm)
PACS SPECTRUM
PACS Spectrum (Line/Continuum)

Lellouch et al 2010, submitted
P(T) and Molecular profiles
HD - PACS

Observations

HD (6-9-12 x 10^{-5})
+ best P(T)

HD (910^{-5})
+ Colder P(T)

H_2O (profile A)

Observations

Δλ = 0.02 μm

Δλ = 0.12 μm
HD - Results

Thermal profile:
P(T) : best profile : 0.9x AKARI+0.1 Voyager (i.e. 3K warmer than Voyager at tropopause)

HD Abundance:
HD /H\textsubscript{2} =9±2 \times 10^{-5}
Since D/H = \frac{1}{2} HD/H\textsubscript{2} \quad \Rightarrow \quad D/H = 4.5±1 \times 10^{-5}

Nominally smaller but consistent with ISO Value (D/H = 6.5±2 \times 10^{-5}, Feuchtgruber et al 1999 )

\Rightarrow \text{Confirms that Neptune is enriched in deuterium compared to the protosolar value (D/H \sim 2.1 \times 10^{-5} on Jupiter and Saturn)}
\Rightarrow \text{Implications on the composition of the icy grains that formed Neptune : (D/H)ice \sim 7 \times 10^{-5} (\sim 1/4 \times \text{Comet D/H} \sim 3 \times 10^{-4} )}
D/H over the Solar system

Bockelee-Morvan et al 1998
**CH$_4$ - PACS**

$\Delta \lambda = 0.12 \, \mu m$

**CH$_4$ ($1.5 \times 10^{-3}$ )**

**CH$_4$ ($1-2 \times 10^{-3}$ )**

**CH$_4$ ($2.5 \times 10^{-3}$ )**

Down to 800 mbar
CH$_4$ - Results

The retrieved stratospheric methane mixing ratio:
\[ q_{\text{CH}_4} = 1.5 \pm 0.2 \times 10^{-3} \]

First precise measurement of CH$_4$ in Neptune’s stratosphere

-smaller than the troposphere value (2%) , because of the condensation at the cold trap.

-nevertheless, exceeds the cold trap saturation value by factor 10

Most probable origin of this elevated value : CH$_4$ leaks from the warmer southern region (i.e. +6K from Orton et al 2007) and is redistributed planetwide by global circulation
H$_2$O – PACS

More than 20 lines of H$_2$O (unresolved)
H$_2$O - Results

The presence of H$_2$O in giant planet stratospheres, including Neptune, was established by ISO, demonstrating the existence of an external oxygen supply, but the water vertical profile could not be determined.

Current best fit of PACS spectrum suggests that H$_2$O increases with altitude from 1 to 0.1 mbar.

→ Water external flux : $1.4 \times 10^5$ cm$^{-2}$s$^{-1}$

To be confirmed by higher SNR line observations (HIFI, PACS)
CO – PACS and SPIRE

Temperature (K)

Pressure (mbar)

Mixing ratio

Line / continuum

Residuals for CO Fletcher
Residuals for CO Lellouch

Observed
CO Fletcher
CO Lellouch

Observed
CO Fletcher
CO Lellouch
PACS and SPIRE confirm that CO abundance is higher by factor 2-4 in stratosphere than in troposphere. This implies a dual external/internal source of CO, with the external source possibly provided by an ancient cometary impact.

Higher S/N SPIRE spectrum will be needed to improve CO profile
CONCLUSIONS

• High quality PACS spectrum, and preliminary SPIRE spectrum were obtained on Neptune.

• HD, CH$_4$, H$_2$O, CO well detected, but no new molecules.

• Additional observations to come:
  - HIFI: H$_2$O at 557 GHz
  - PACS: Dedicated H$_2$O line scans
  - SPIRE: Higher S/N spectrum

• These observations + combined analysis with SPITZER and AKARI will allow to refine the P(T) and molecular abundances